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LATE TERTIARY MARINE TRANSGRESSION IN THE BRISBANE RANGES, VICTORIA

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Abstract: The recent discovery of fragmentary marine fossils in the Moorabool Viaduct Sand in the Brisbane Ranges extends the area of known late Tertiary marine transgression of the Otway and Port Phillip Basins. A fossil shore platform exhibiting the ichnogenus *Trypanites* Magdefrau 1932, and rock borings attributed to Pholadid bivalves, is exposed in road cuttings on the Ballan-Geelong Road and provides further evidence of shallow marine conditions in this area in the late Tertiary.

For much of the Tertiary the Brisbane Ranges area appears to have been exposed, forming the hinterland to the marine basins. Its submergence in the Late Miocene-Early Pliocene was followed by marine regression and fluvial sedimentation in the Pliocene. The Moorabool Viaduct Sand was deposited during this transgressive-regressive episode. Local tectonics, coupled with eustatic sea level changes have influenced the distribution of Tertiary marine sedimentation in both the Brisbane Ranges and other areas surrounding Port Phillip Bay.

Extensive deposits of flat lying ferruginous sandstone and minor conglomerate form hill cappings in the Anakie, Steiglitz and Meredith areas to the west of Melbourne (Fig. 1). Similar ferruginous deposits outcrop east of the Rowsley Fault around the You Yangs, but are largely covered by Plio-Pleistocene basalts and alluvial sediments. The sediments are generally poorly exposed, but appear to be continuous with similar ferruginous deposits comprising parts of the Moorabool Viaduct Sand in the Geelong district (Fig. 1). They are therefore referred to the Moorabool Viaduct Sand. Most studies of Tertiary sediments in this area have concentrated on the marine sequences at Maude and to the south (e.g., Hall & Pritchard 1892, 1895, 1897, Doust 1968) although Harris & Thomas (1948) and Bowler (1963) briefly discussed the ferruginous sediments north of Maude.

The Tertiary sediments in these areas were deposited in the Otway and Port Phillip Basins on, and adjacent to, bedrock comprising Ordovician low grade metasediments and Upper Devonian granite. The area of Ordovician bedrock on the uplifted western side of the Rowsley Fault is here referred to as the Brisbane Ranges Block (Fig. 1). The purpose of this paper is to discuss the limits of marine transgression to the north of Maude during the late Tertiary, and to describe the angular unconformity between the Moorabool Viaduct Sand and Ordovician bedrock exposed near Anakie.

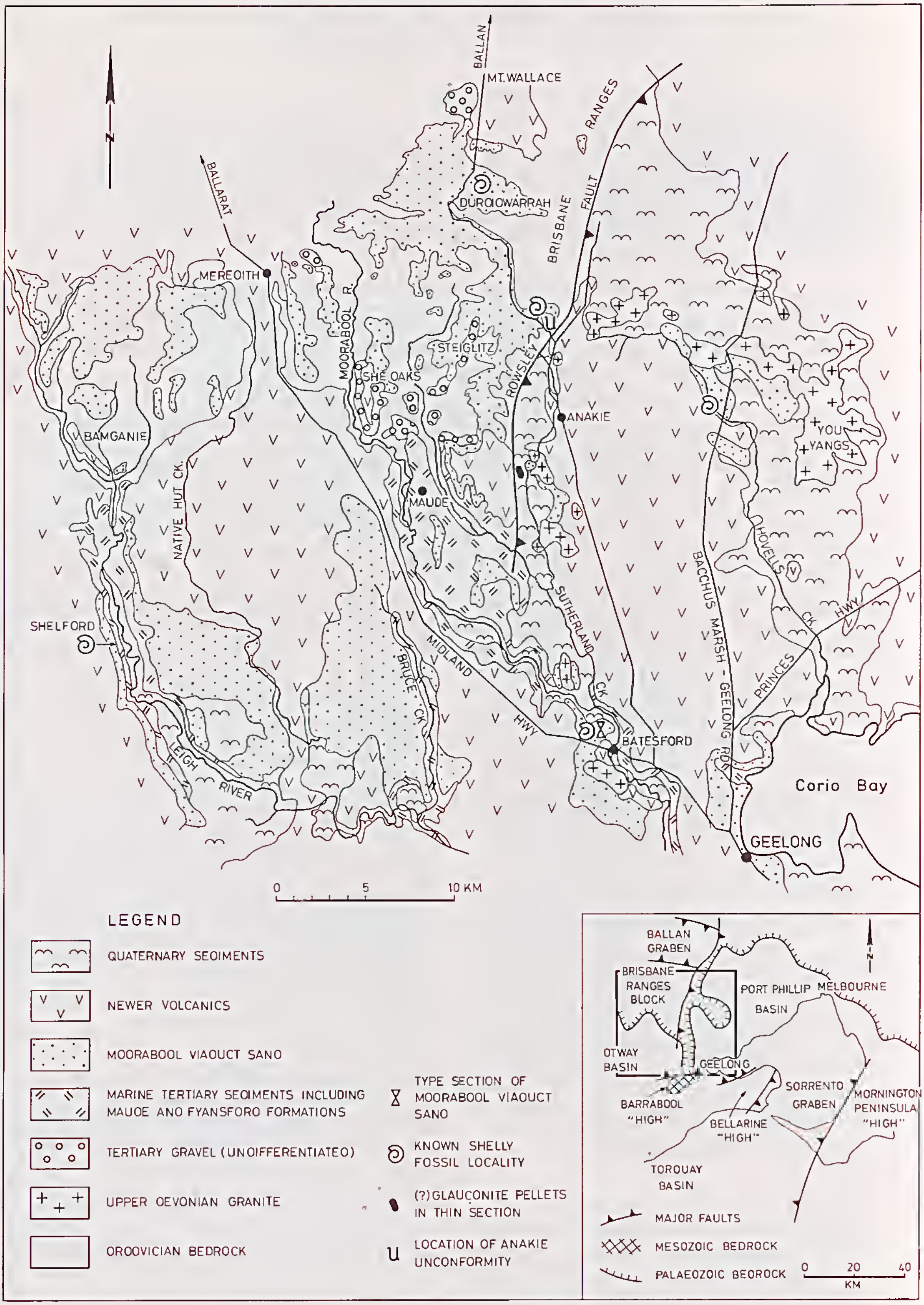
MOORABOOL VIADUCT SAND

Lithology

At its type locality 2.5 km north of Batesford where the Geelong-Ballarat railway line crosses the Moorabool River (Fig. 1), the Moorabool Viaduct Sand comprises an upper sandy unit overlying iron-stained fossiliferous calcareous sand and sandy calcarenite. In the area north of Maude, the calcareous facies is absent and the Moorabool Viaduct Sand consists mostly of moderately to well sorted, fine to coarse sand and sandstone with minor gravel and conglomerate. The sandstones are thinly bedded with planar bedding, rare graded bedding, small channels and planar and trough cross-stratification. The sediments are sometimes unconsolidated, but are usually strongly cemented by iron oxides. The sandstones consist of well rounded to angular common ("plutonic") quartz and minor feldspar, micas and heavy minerals. The angular quartz grains are usually intensely corroded by the ferruginous cement. The maximum exposed thickness in this area is 16 m along Sutherland Creek (east branch) where at one locality the sands contain well-rounded structureless ferruginous pellets of (?) oxidised glauconite. Fine to coarse grained gravel, rarely more than 3 m thick, occurs at the base of the Moorabool Viaduct Sand at some localities. The gravel contains subangular to very well rounded clasts of vein and common ("plutonic") quartz, slate, some sandstone and rare granite clasts. The gravelly beds grade vertically into the ferruginous sand and sandstone. Auriferous well rounded gravel occurs at the base of the Moorabool Viaduct Sand at Steiglitz.

Palaeontology and Age

In the area north of Maude the fossils collected in the Moorabool Viaduct Sand are either fragmentary or too long ranging for an accurate age determination. Marine shelly fossils of late Tertiary age have been found near Durdidwarrah (Darragh *in* Makram & Neilson 1970, and pers. comm. 1977). Ferruginous moulds of gastropods, foraminifera and very rare bryozoans have been found in sand outcropping in the road cuttings on the Geelong-Ballan Road near Anakie, while gastropod fragments occur in sediments east of the Rowsley Fault near the You Yangs. Wood fragments were found at a number of


N
BALLAN
MT. WALLACE
RANGES
BRISBANE FAULT
BALLARAT
DUROIDWARRAH
MEREDITH
MOORABOOL R.
STEIGLITZ
ROWSLEY
SHE OAKS
ANAKIE
BAMGANIE
NATIVE HUT CK.
MAUDE
YOU YANGS
HOVELLS CK
SUTHERLAND CK
BACCHUS MARSH - GEELONG RD
SHELFORD
MIDLAND HWY
BRUCE CK
PRINCES HWY
BATESFORD
LEIGH RIVER
Corio Bay
GEELONG
0 5 10 KM
LEGEND
QUATERNARY SEDIMENTS
NEWER VOLCANICS
MOORABOOL VIADUCT SAND
MARINE TERTIARY SEDIMENTS INCLUDING MAUDE AND FYANSFORD FORMATIONS
TERTIARY GRAVEL (UNDIFFERENTIATED)
UPPER DEVONIAN GRANITE
ORDOVICIAN BEDROCK
TYPE SECTION OF MOORABOOL VIADUCT SAND
KNOWN SHELLY FOSSIL LOCALITY
(?) GLAUCONITE PELLETS IN THIN SECTION
LOCATION OF ANAKIE UNCONFORMITY
BALLAN GRABEN
BRISBANE RANGES BLOCK
PORT PHILLIP BASIN
MELBOURNE
OTWAY BASIN
GEELONG
BARRABOOL "HIGH"
BELLARINE "HIGH"
SORRENTO GRABEN
MORNINGTON PENINSULA "HIGH"
TORQUAY BASIN
MAJOR FAULTS
MESOZOIC BEDROCK
PALAEOZOIC BEDROCK
0 20 40 KM

localities. Hall & Pritchard (1897) recorded leaf moulds and Doust (1968) recorded oyster shells and moulds of molluscs and leaves from localities to the south of Maude. Dennant and Mulder (1896) discovered marine shelly fossils in a ferruginous conglomerate at Shelford 20 km to the southwest of Maude. The fauna includes *Chlamys antiaustralis* and *Tylospira coronata* suggesting a Cheltenhamian (Late Miocene) age (Darragh *in* Abele *et al.* 1976). In the type area near Geelong, the Moorabool Viaduct Sand is of Late Miocene to Early Pliocene age (Darragh *in* Abele 1976). A similar age is inferred for the beds at Anakie and Durdidwarrah.

Stratigraphic Relationships

In the area south of Maude, the Moorabool Viaduct Sand disconformably overlies the marine, Middle Miocene Fyansford Formation: the disconformity is commonly marked by a phosphatic nodule band (Bowler 1963).

The Moorabool Viaduct Sand capping the hills north of Maude rests with marked angular unconformity on steeply dipping Lower to Middle Ordovician sandstone and slate. The unconformity exposed near Anakie is described below. Around the southern margins of the You Yangs, the Moorabool Viaduct Sand wedges against the You Yangs Granite and is locally enriched in feldspar and biotite derived from the granite.

At Sheoaks, Steiglitz, Meredith and near Mt Wallace, ferruginous sandstone and conglomerate referred to the Moorabool Viaduct Sand overlie fluviatile gravel, sand, silt and clay. The fluvial deposits are considered to be of Tertiary age although they cannot be dated more accurately.

THE UNCONFORMITY AT ANAKIE

The Unconformity Surface

The unconformity is exposed in two road cuttings 5 km north of Anakie on the Ballan-Geelong road. It is an irregular surface cut into a sequence of steeply dipping, tightly folded Ordovician slate and thin sandstones with occasional thicker sandstone beds, which are overlain with strongly anguar unconformity by a basal conglomerate and fine to medium grained quartzose sands of the Late Miocene-Early Pliocene Moorabool Viaduct Sand. The unconformity is exposed over an east-west distance of 30 m, and has an observed maximum relief in the order of about 8 m in the western end of the cutting where there is a large gutter 8 m wide at the base, eroded into a thick sandstone interval forming the core of a tight anticline (Fig. 2). Small scale relief is typically in the form of small fissures or gutters, the formation of which has been controlled by preferential erosion along bedding, cleavage or fault planes.

The Moorabool Viaduct Sand

The lowermost deposit of the Moorabool Viaduct Sand upon the unconformity surface is a basal conglomerate, confined mainly to the large gutter, smaller gutters and depressions (Fig. 2). This is overlain by a dominantly fine to medium grained quartzose sandstone. The sandstone overlies and abuts the higher areas of the unconformity surface where the conglomerate was not deposited (Fig. 2).

The Basal Conglomerate

The basal conglomerate consists of clasts of rounded to less commonly angular to subangular pebbles and cobbles of white vein quartz, rounded pebbles, cobbles and boulders of quartzite and quartz sandstone, rounded, weathered clasts of granite up to 85 cm maximum diameter, pebbles of ironstone containing angular grains of common ("plutonic") quartz, fresh feldspar and rare shelly impressions, and angular to subrounded slate clasts ranging from granule to large boulder grade. The matrix to the conglomerate is a medium to very coarse grained sand, with granule grade detritus to 0.5 cm, consisting of both white and clear quartz, feldspar, rounded platy slate fragments, and rare biotite, with a secondary whitish clay matrix. The granite clasts include an 85 cm maximum diameter medium grained leucogranite, consisting of quartz and feldspar with minor white mica and biotite, and a 70 cm maximum diameter coarse grained quartz-feldspar-biotite granite (with kaolinised phenocrysts of feldspar to 1 cm). The latter is associated with clasts of a much finer grained, less than 1 mm, aplitic phase speckled with fine biotite. The slate clasts range from platy, rounded sand and granule sized fragments up to more angular blocks about 0.5 m × 1.3 m. The largest slate blocks occur in the deep gutter cut into the Ordovician sandstone. On the western side of this gutter slate blocks can be observed strongly tilted but not quite broken off the palaeo-outcrop and subsequently buried by sands of the Moorabool Viaduct Sand. The larger slate clasts tend to lie with their maximum projection plane subparallel to the unconformity surface although small clasts are randomly oriented.

The Sandstones

The sandstones overlying both the basal conglomerate and in places the unconformity surface are typically fine to medium grained, occasionally coarser grained, quartz arenites (*sensu* Okada 1971), which grade upwards from the basal conglomerate. Ferruginous moulds of benthonic foraminfera, especially miliolids, small gastropods and very rare bryozoans are contained in the sandstone unit. The sands exposed above the unconformity and in road cuttings to the west display low angle cross lamination and planar lamination. The sandstone occasionally contains scattered, typically rounded granule and pebble grade quartz, slate and occasionally granite clasts up to 30 cm. These larger clasts usually occur within the lower intervals of the sand where it overlies the basal conglomerate, or adjacent to higher areas of the unconformity surface against which the sand abuts. The finer clasts in places define a

Fig. 1—Geological Map of the Geelong-Meredith area (after Geological Survey of Victoria 1:250 000 Melbourne, Queenscliff, Colac, Ballarat maps).

Fig. 2—Detail of the unconformity exposed in the road cutting, Ballan-Geelong Road, Anakie, showing the basal conglomerate and sandstone of the Moorabool Viaduct Sand, *Trypanites* distribution and structural control of conglomerate distribution.

Fig. 3—*Trypanites* Magdefrau 1932: sectional view of borings exposed on the broken surface of a fragment of a slate clast from the basal conglomerate.

subhorizontal stratification, of granule-rich and granule-poor layers.

Trace Fossils

Cylindrical holes may be observed in the slate of the unconformity surface and in the slate blocks of the basal conglomerate (Fig. 2). The holes are circular in transverse section, ranging in diameter from a few millimetres to 2 cm. In longitudinal section they are cylindrical to conical in shape, up to 4.5 cm deep, and with a hemispherical base (Fig. 3). No internal markings were observed, other than due to cutting the slaty cleavage, and fine pitting due to weathering of the slate. One hole was noted to have a small rim 2 mm high of cemented fine sand. The concentration of holes per unit area of rock is highly variable. They are commonly oriented perpendicular to the surface of the unconformity or the slate blocks but may be oblique. The latter orientation is more common in areas of higher density. With the burial of the unconformity surface and basal conglomerate by sands of the Moorabool Viaduct Formation many of the holes became infilled with sand. Some holes still contain their sand filling, while in one instance the slate has been weathered away to leave bulbous cemented sand casts of the holes on the base of the overlying sandstone.

The holes are considered to be borings, and are ascribed to the ichnogenus *Trypanites* Magdefrau 1932 (Bromley 1972). The borings in this instance are most probably due primarily to bivalves of the Family Pholadidae. The morphology of the borings compares closely with that described for present day pholadid borings by Evans (1970). Furthermore, they closely resemble pholadid borings figured by Evans (1970, pl. 7) and Warme (1970, pl. 2).

Most holes have been modified by abrasion subsequent to their formation. This modification has probably been accentuated by recent weathering. Abrasion has resulted in borings with a shorter longitudinal axis and a wider than normal opening. All that remains of some borings is the hemispherical base. Boring pholadids will avoid breaking into an adjacent boring, and will either divert or cease boring leaving a wall which may be as thin as 1 mm (Evans 1970). Abrasion has resulted in many of these walls in areas of close boring being worn away, producing a merging of holes. The abrasive effect of water and sediment on the borings has more than likely resulted in widening of holes, as well as the destruction of common walls, and the obliteration of any internal markings which may have been present. Abrasion may also have been responsible for the obliteration of finer, smaller borings and the modification of larger borings, so as to prevent recognition of the presence of other boring organisms, and assignment of some of the holes to organisms other than pholadid bivalves.

Discussion and Interpretation of the Unconformity

The presence of borings attributed to pholadid bivalves and the occurrence of marine fossil fragments within the basal sands of the Moorabool Viaduct Formation indicate the existence of marine conditions during deposition on the unconformity surface. The unconformity surface is interpreted as a wave-cut platform formed during the Late Miocene transgression. The large gutter eroded into the sandstone, and the smaller gutters eroded along bedding, cleavage or fault planes are considered to have been cut by preferential erosion along these zones of weakness by the action of breaking waves and backwash. As clasts accumulated within the depressions their to and fro movement by the wave and backwash action assisted in further erosion of the channels and gradual rounding of the clasts.

The basal conglomerate is a littoral-zone or strandline conglomerate deposited within depressions and channels cut into the wave cut platform. As is typical with such conglomerates, much of the detritus is of very local derivation. The slate clasts are obviously derived from the underlying Ordovician, while the vein quartz, quartzite and quartz sandstone clasts are almost certainly derived by erosion of the Ordovician bedrock. The large blocks of slate within the major gutter are considered to have been broken off the slate outcrop marginal to this gutter. In the slate outcrop on the western margin of the gutter there is a strongly tilted block of slate which was in the process of being loosened from the outcrop when burial by the Moorabool Viaduct Sand occurred. The granitic clasts are within the range of variation of the Devonian granites in the Anakie area outcropping east of the Rowsley Fault, and were probably derived from them.

As the transgression proceeded, it was probably followed close behind by the establishment of a rocky shoreline biota. This included at least pholadid bivalves, which inhabit the rocky substrate of intertidal and subtidal environments (Evans 1970). These organisms established habitats by boring into the unconformity surface and the slate blocks upon this surface. The occurrence of deeply abraded borings with partially or non-abraded borings indicate alternating periods of abrasion and boring activity. This is most probably due to periods of heavy wave activity, abrading the unconformity surface and slate blocks with finer gravel and sand, and probably also moving the larger slate blocks about within the gutter. During periods of more normal conditions the bivalves would re-establish their habitat, with new borings being formed amongst the earlier, abraded ones.

With time, the unconformity surface and basal conglomerate were buried by sand, and the rocky substrate biota displaced. The sands are well sorted, with horizontal and low angle cross-stratification typical of very nearshore and beach deposits (Clifton *et al.* 1971). The environment therefore remained at or very close to shoreline. Subsequently the transgression ceased and regression began, although it has not been possible to determine whether the highest beds in the outcrop at Anakie are transgressive or regressive sands.

SEDIMENTARY ENVIRONMENTS AND REGIONAL EXTENT OF MARINE TRANSGRESSION

The intense ferruginisation and poor exposure of the Moorabool Viaduct Sand throughout the area examined does not lend the unit to detailed facies analysis. Nevertheless both marine and non-marine facies are recognised locally. The inferred distribution of these facies, is shown in Fig. 4.

Calcareous marine facies have been described in the type area of the Moorabool Viaduct Sand in the Geelong district (Hall & Pritchard 1897, Singleton 1941, Bowler 1963, Doust 1968). All the ferruginous sediments north of Maude have previously been regarded as non-marine deposits (Harris & Thomas 1948, Bowler 1963). However the occurrence of marine shelly fossils at Durdidwarrah (Darragh *in* Makram & Neilson 1970 and pers. comm. 1977) indicates that the maximum marine transgression extended further north than was previously recognised. This is further supported by the occurrence of marine shelly fossils and a demonstrable fossil shoreplatform in the Durdidwarrah-Anakie area. Elsewhere recognition of marine facies is difficult.

East of Anakie probable marine strata abut the You Yangs Granite. Around the southern margin of the You Yangs near the Bacchus Marsh-Geelong Road, well sorted, planar-bedded medium to very coarse sands, locally containing well rounded frosted quartz grains, wedge against the granite. These deposits may be beach sands. Very rare gastropod moulds and ovoid limonitic pellets were found at one locality in this area, although it is not certain whether the gastropods are marine or non-marine forms. The limonitic pellets may be faecal pellets. Along Sutherland Creek (east branch) there are tabular and trough cross-stratified medium to coarse sands also containing abundant ferruginous pellets which may be oxidised glauconite or ovoid faecal pellets suggesting a possible marine origin for the sediments. These deposits are neither well sorted nor well rounded and may represent sand accumulation in offshore sand waves. The indirect evidence suggests that the beds exposed marginal to granitic outcrops east of the Rowsley Fault are probably shallow marine or shoreline sands deposited adjacent to and onlapping a granitic coastline which suffered erosion and provided detritus for the sands around the granitic coast and the conglomerate at Anakie.

In the southwest of the area, fossiliferous marine strata are recognised at Shelford. North of Shelford near Bamganie, the sediments are unfossiliferous and although they are texturally mature and contain ferruginous grains which may be oxidised glauconite pellets, there is no conclusive evidence for marine transgression in this area.

Fluvial facies in the Moorabool Viaduct Sand are recognised by the local occurrence of plant remains in sands and the presence of lenticular trough cross-bedded gravels. Ferruginous lenticular gravel deposits referred to the Moorabool Viaduct Sand overlie unconsolidated Tertiary fluvial deposits at a number of localities in the

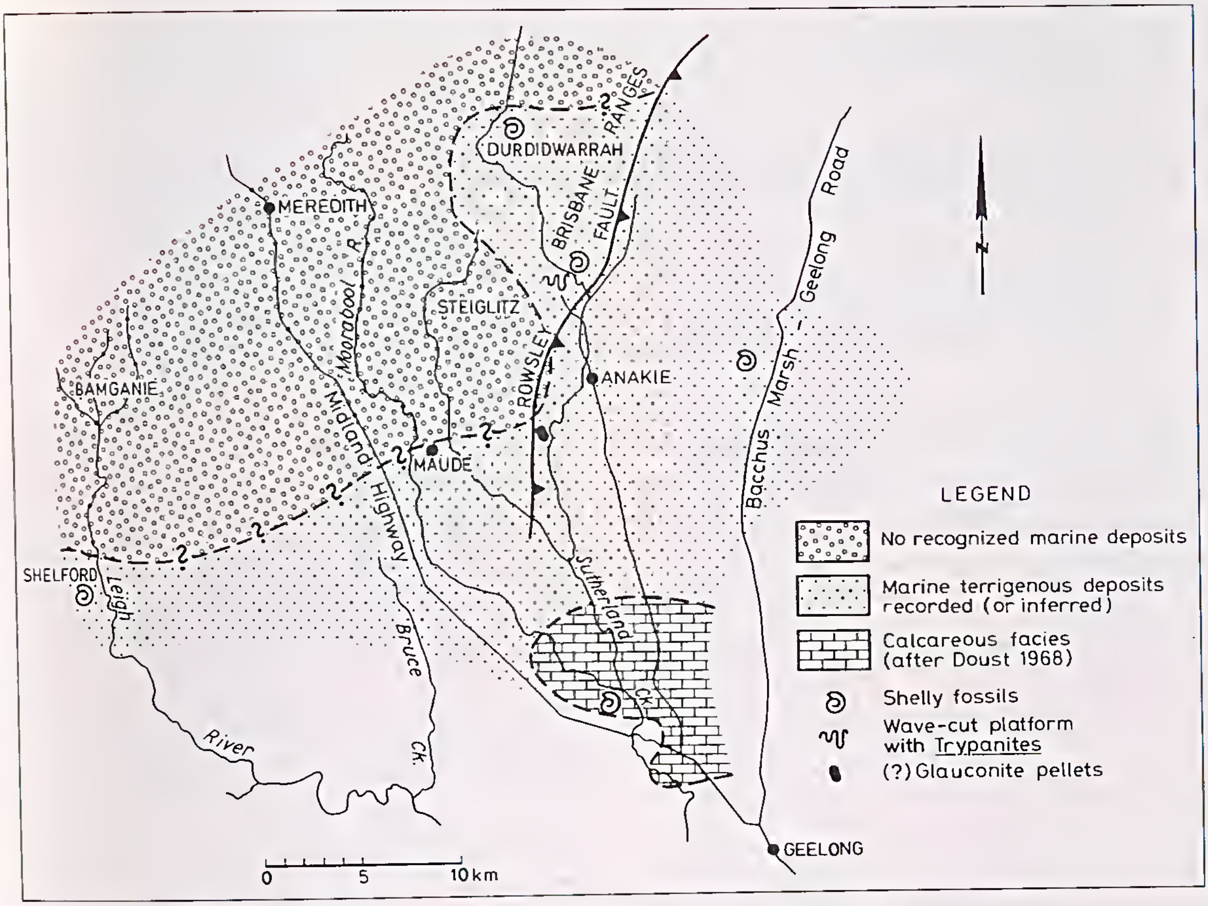


Fig. 4—Distribution of marine and non-marine facies of the Moorabool Viaduct Sand.

Mount Wallace, Meredith and Steiglitz areas and are overlain by both marine and non-marine ferruginous sands.

CONCLUSIONS

Throughout much of the Tertiary, the Brisbane Ranges Block was a topographically positive area forming the hinterland to the Otway and Port Phillip Basins (Fig. 1). Oligocene to Middle Miocene marine transgression in the Otway Basin extended as far north as Maude where shoreline desposits of the Maude and Fyansford Formations are exposed (Bowler 1963, Doust 1968, Bolger 1977). In other areas of relative uplift in the Port Phillip district (e.g., the Bellarine and Mornington Peninsula Highs), marine regression occurred in the Late Miocene (Holdgate 1976). Climatically induced Late Miocene marine regression caused shallowing of the sea in the Sorrento Graben, although sedimentation continued without a break (Mallett 1978).

In the Late Miocene-Early Pliocene shallow marine sedimentation continued in the Sorrento Graben (Holdgate 1976, Mallett 1978) while the Bellarine High (Bowler 1963) and the Brisbane Ranges Block underwent marine transgression. The transgression extended as far north as Durdidwarrah on the Brisbane Ranges Block, eroding a rocky shore platform at Anakie and depositing the marine facies of the Moorabool Viaduct Sand. Marine transgression also occurred on the eastern side of Port Phillip Bay depositing the Black Rock Sandstone (Singleton 1941, Kenley 1967, VandenBerg 1973).

During later Pliocene times marine regression and fluvial sedimentation occurred on the "Highs" marginal to Port Phillip Bay, while shallow marine sedimentation continued in the Sorrento Graben (Holdgate 1976). Subsequent uplift along the Rowsley Fault has raised the Brisbane Ranges to their present elevation, and tilted the Newer Volcanics. In the east of Port Phillip the fluvial sediments are known as the Red Bluff Sand (Kenley 1967, VandenBerg 1973).

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